NASA TECHNICAL TRANSLATION

NASA TT F-14,113

THE HUMAN BODY AND VIBRATIONS

Alain Berthoz

Translation of "Le Corps Humain et les Vibrations," Le Recherche, Vol. 2, No. 9, February 1971, pp. 121-129.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546 FEBRUARY 1972

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ABSTRACT: The mechanical impact of vibrations on biological receptors is summarized. Debilitating mechamisms and their results are examined in view of clinical tests on animals and human subjects. Application to therapeutic and scientific research is also discussed.

INTRODUCTION

The greater and greater role played by means of transportation and motor equipment in daily life has opened a new chapter in human pathology: troubles caused by vibrations. They range from simple "seasickness" to very grave afflictions leading to invalidism. /121*

The effects of vibrations on the human body are studied by numerous private and national organizations which essentially propose the establishment of national norms defining the vibration levels which a healthy body can tolerate. On the international level this poses important problems at the present time in standardizing experimental techniques and equipment which, under the impulse of acquired knowledge, continued to become more diversified and to be refined in a still anarchical way. A piece of equipment constructed in confirmity with national norms can be considered perfectly unacceptable by other countries. In July 1970 representatives from 53 countries met within the framework of the International Standardization Organization in order to normalize terminology, equipment and techniques.

Beyond this "minimum safety" research, standard at any rate in a curiously uneven way according to the professional categories involved, the basic data acquired permit us to see some use of vibrations for purposes beneficial to man, both in the strictly therapeutic domain and in provision for aid to deficient senses, such as sight.

*Numbers in the margin indicate pagination in the foreign text.

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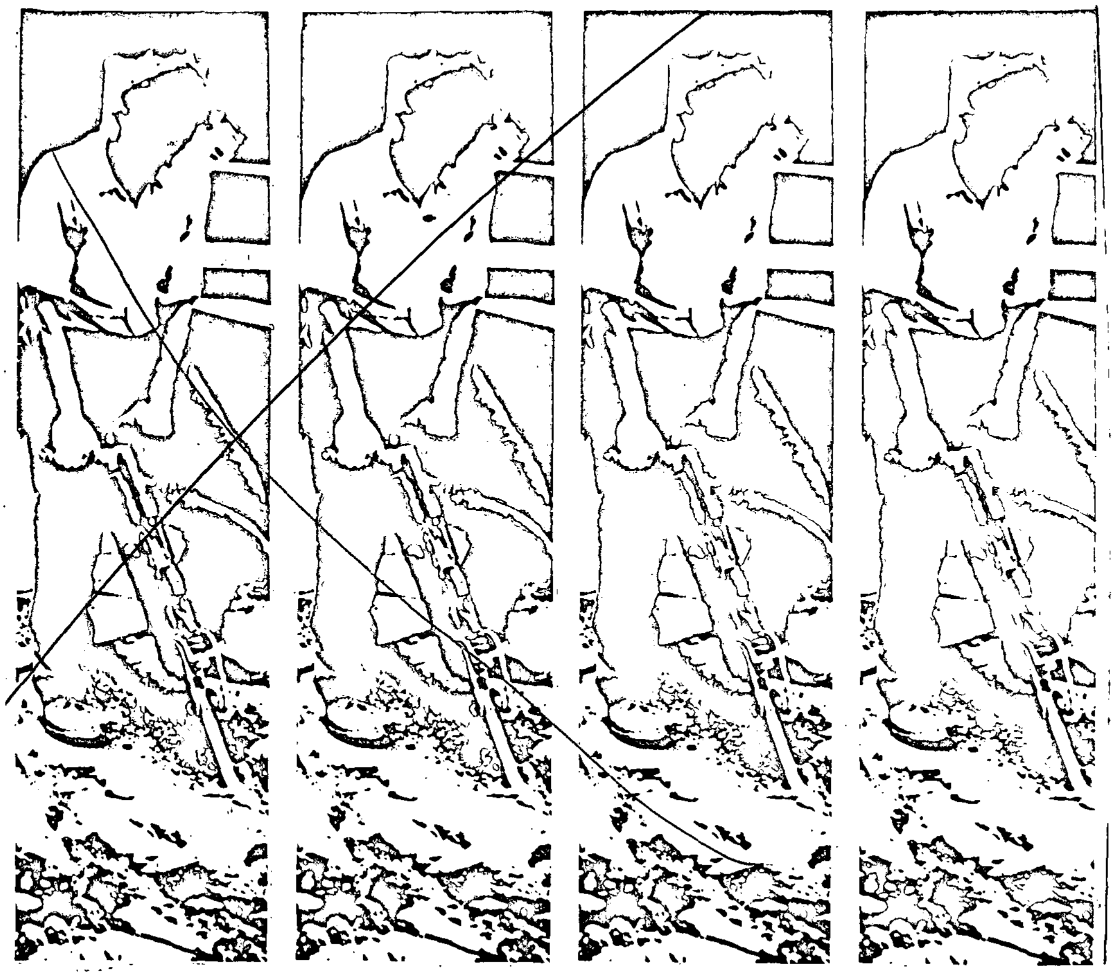


<u>The Labyrinth, Situated in the Inner Ear, Contains a Group of Receptors Which Are Sensitive to Very Low Frequency Vibrations</u>

For several decades, chiefly as a result of the propagation of land and air means of transportation, all the industrialized countries have seen the development of research on the effects of a very special category of vibrations, those caused by the movement of solids in direct contact with the human body. These "mechanical" vibrations are prosaically called "vibrations," which has caused a certain amount of confusion. A mechanical vibration can indeed give rise to fluctuations in air pressure to which the pseudonyms of sounds, ultrasounds and infrasounds had been given, depending upon whether their frequency is within the sensitive range of the ear or not. This category of vibrations, transmitted through the ear, will be omitted in what follows. The vibrations involved here are only the movements transmitted to the human body with no intermediary. Other types of confusion come from the fact that these wave movements can be slow (low frequency) or follow in rapid succession (high frequency), simple (sinusoid) or complex (contingent), and can operate in a single spatial direction or in several. Thus the slow movement of a boat, the trot of a horse, and walking are just as much vibratory phenomena as the vibration of a motor.

In order to satisfy the requirements of scientific study it has been necessary to put some order into this apparent variety of phenomena. In a recent treatise dedicated to the physiology of work and ergonomics [1], A. Wisner summarizes the state of information on the effects of mechanical vibrations. The author proposes dividing vibrations into three categories depending upon whether their frequency is low (0 to 2 Hz), medium (2 to 20 Hz), or high (>20 Hz).

In what follows, various justifications will be found for this distinction. But in order to gel the ideas, here are some examples. First of all the human body is a heterogeneous collection of organs, supporting tissues and bony structures which transmit exterior variations in force like any physical system. These tissues and organs behave like filters which amplify the vibrations of certain frequencies and damp the others. In addition, although man can tolerate his body being submitted to oscillations of several meters in amplitude at a frequency of 0.5 Hz without pain, this amplitude has to be reduced to several millimeters at 5 Hz and to a few microns at 500 Hz. Within these limits one factor introduces still another essential difference among the effects produced by various frequencies: this is the sensitivity of the physiological mechanical receptors. The semicircular canals of the inner ear are only sensitive to very slow movements, while the muscular receptors are capable of transmitting nervous signals which "follow" oscillations extending up to 200 Hz; finally certain cutaneous receptors are sensitive only to dynamic variations with a frequency between 40 and 1,000 Hz.

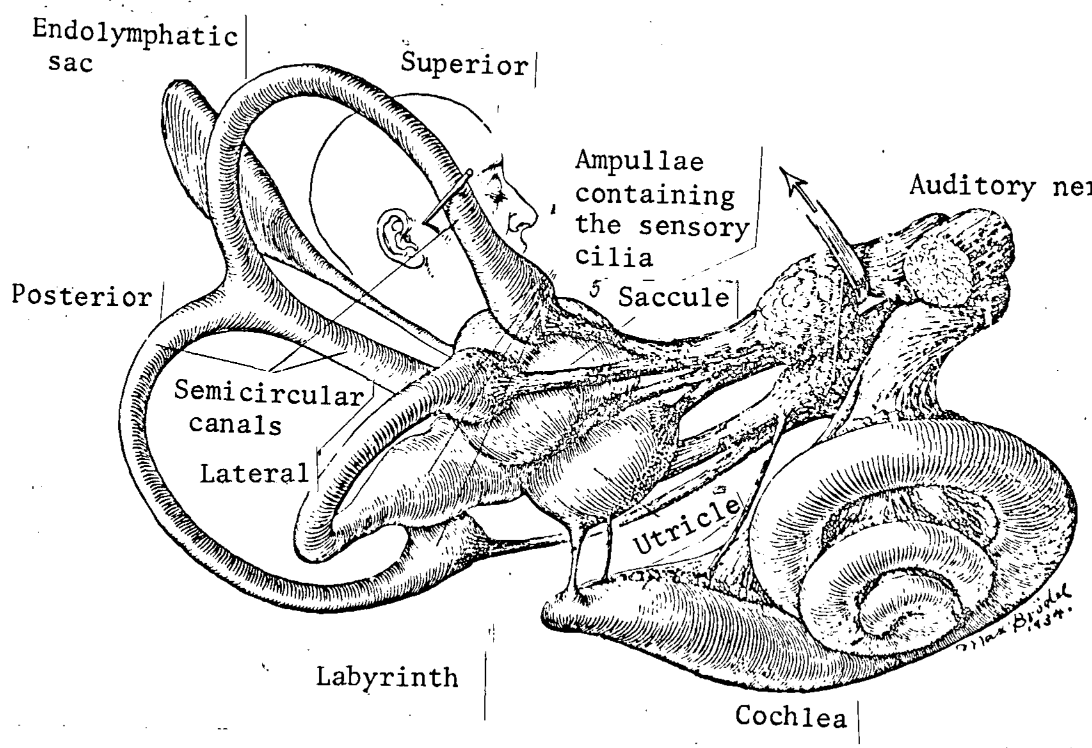


Figure 1. Receptors of Acceleration and Position, The Labyrinth are Particularly Sensitive for Informing the Central Nervous System about Oscillating Movements of the Head Because of the Sensory Cilia of the Receptors Contained Respectively in the Semicircular Canals and in the Saccule and the Utricle. The nerves coming from each part of the labyrinth transfer information relative to direction and intensity of movement. The marker placed near the ear indicates the orientation of the drawing with respect to the head. (According to Hardy [8].

Thus, not only the perception of these categories of vibrations but also the pathological difficulties which they cause and even the technical means used to study them are different.

It is not our purpose here to paraphrase A. Wisner's work. We shall briefly review his main ideas and concern ourselves chiefly with some recent research carried out on both man and animal in both real life and in the laboratory.

Motion Sickness and the Labyrinth /123

When the oscillating movements are of a moderate amplitude and are produced at frequencies lower than 1 or 2 oscillations per second (0-2 Hz), the skeletal musculature can easily compensate for the forces applied to it. Under these conditions the human body behaves approximately like a solid mass. Nevertheless, serious troubles can be associated with these oscillations. The best known is motion sickness which has its origin in the activity of a specialized organ, the labyrinth, situated in the inner ear. For a long time it was thought that this organ was a sort of relic with minimum importance. In reality, although in man its role is minimized by the powerful controls which the cortex and other parts of the brain exercise on it, it is still a very complex receptor and still poorly described. It is in direct contact with the control of eye movements and of the position of the body in space. Curiously its role seems to increase along with the publication of experimental results and its study promises to be fascinating. Composed essentially of two groups of receptors which measure acceleration variations, its functioning is similar to inertial controls which guide airplane flight.

Recently a particular effort has been made to understand the mechanisms of transduction. The latter is assured by receptor cells composed of a cellular body and sensory cilia which are shifted when the head is moved by the displacement of a liquid (endolymph) situated in the labyrinth organs. These cilia are of two types, stereocilia and kinocilia: they differ in number (only 1 kinocilium per cell), in properties and in function. It is known now that the sensory cilia are arranged according to a strict geometry and that an identical type of receptor is present in the different parts of the labyrinth. In opposition to theories which attribute a role in transduction to all of the cilia of a receptor cell, there has recently been proposed [2] another interpretation:

only the kinocilium would act as a "plunger" under the effect of the pressure of the other cilia. At the present time these hypotheses are limited to research on animals (frog, squirrel, cat). This gives an idea of the path to be followed before the mechanisms intervening between the receptor and the final effect are understood well. The most significant progress is achieved at the present time by the simultaneous use of electrophysiology and the electron microscope. Two other essential results have been obtained during the last few years. On the one hand, it has been shown in the cats that not only does each labyrinth activate the neurons of the ipsilateral vestibular nucleus, but also that it inhibits the contralateral vestibular necleus [3]. Thus, there is undoubtedly a very subtle reciprocal organization with ramifications extending to the oculomotor nuclei. The other discovery was that of the ef- /124 ferent control [4]: it has now been established that in various species, the receptor cells of the labyrinth are subject to the action of probable inhibiting nerval terminations coming from the cerebral trunk. The function of this efferent system is still unknown, but its discovery will contribute in an important way to a better understanding of the means by which the position of the head and of the body in space is assured. Teams working in many countries are contributing to this work, but it would be rather delicate to give a restrictive list.

Oscillation Frequencies From Most Terrestrial Vehicles are Just the Most Dangerous Ones

In man, research on the effects of vestibular stimulation have been predominantly the act of both clinicians and researchers very stimulated by the funds put at their disposition at the time of the space programs.

The effort made in the United States by the Naval Aerospace Institute at Pensacola (Florida) deserves mention. For five years this Institute has been organizing symposia by assembling the greatest specialists in the world on the subject of the "role of vestibular organs for orientation in space." These meetings have played a very favorable role in the constitution of what will certainly soon be an important chapter in the study of man in action. In particular, the problem of motion sickness has been understood more clearly for two or three years [5]. Its origin in the labyrinth is indisputable:

The existence of labyrinth connections with the vegetative nervous centers certainly explain the nature of the sumptoms observed (nausea, vomiting), and the bandpass of the vestibular centers is such that it limits the appearance of difficulties to very low frequencies (1 Hz). The two great properties of this system still being studied are habituation, i.e., the disappearance of systems with training (or the repetition of voyages, for example), and adaptation, i.e., the disappearance of the effect when the stimulation persists. The role played in these two mechanisms by the receptors on the one hand and the central organization of the vestibular reactions on the other hand has not yet been specified, although adaptation is surely a property of the receptors.

But, as a matter of fact, the action of low frequency vibrations on the labyrinth does not completely explain the mechanism of motion sickness, since it is enough to stare at the horizon to damp the symptoms. Nausea is undoubtedly the result of difficulty for the central nervous system to integrate data from proprioceptive, visual and labyrinthic origin which may not correspond; e.g., when one reads a book in an automobile (vestibular oscillation, immobility of visual space). A second family of results observed are the oculomotor and visual effects: when a person is subjected to rotation or to slow oscillation, nystagmus is observed, the succession of movements of the eyes in opposite directions, slow in the direction opposed to rotation and then rapid in the direction of rotation. The mechanism of nystagmus is still unknown. Originating in the labyrinth, it is used for clinical exploration to detect neurological problems. Another phenomenon observed during, or just after, rotation or acceleration is oculogyric illusion: objects in the environment seem to move; this illusion of vestibular origin lasts for quite a long time after stimulation. It is particularly clear in the dark or at night when a person looks at a shining object.

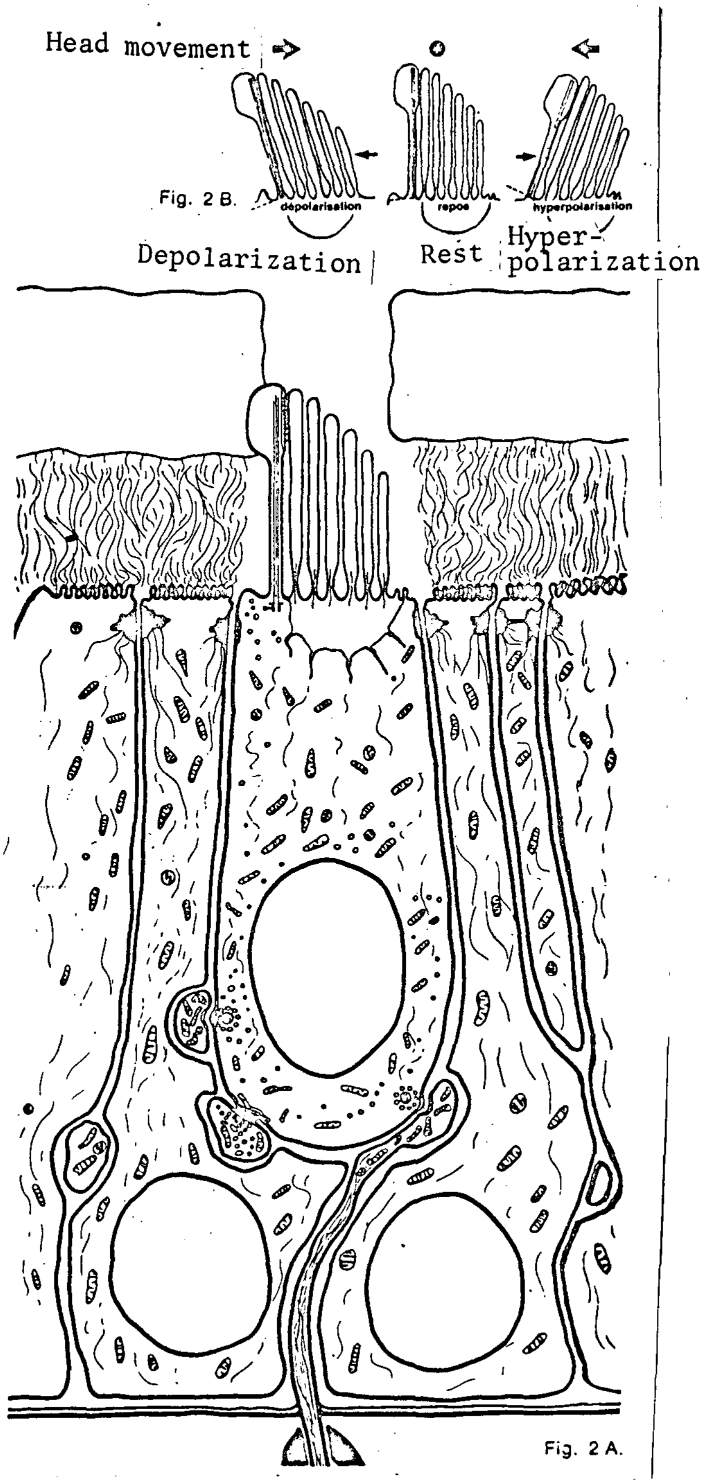


Figure 2. Sensations of Vestibular Origin Cuased by Slow Oscillations, Such as Those Which Cause Motion Sickness, Depend Primarily on the Properties of the Receptors. Therefore, it is essential to know the transduction mechanism of these oscillations on the level of the labyrinth receptors well.

Figure 2a. This Drawing of a Receptor Cell (CB) of a Frog Otolith, According to Photographs Taken with the Electron Microscope, Shows the Sensory Cilia; Kinocilium and Stereocilium (S). They are squeezed into a compact mass, the otolithic membrane (MO), above which is found a cluster of crystals (not shown in the drawing). If the head moves, inertial forces cause the movement of the otolithic membrane which in turn shifts the sensory cilia toward the left or right (shearing). A support cell has been drawn (CS). An efferent nerve ending (E) acts on the cell from the central nervous system; the role of these endings is unknown. (A) is an afferent fiber which conducts perceptions of the receptor cells to the brain.

Figure 2b. Movements of the Head Cause a Hyperpolarization or a Depolarization of the Receptor Cell as a Consequence of the "Plunger" Movement of the Kinocilium and Vary the Discharge Frequency in the Afferent Vestibular Nerve (A), Which Thus Transmits Data on Cilia Movement to the Nervous Centers of the Main Trunk and Brain (According to Hillman, 1969).

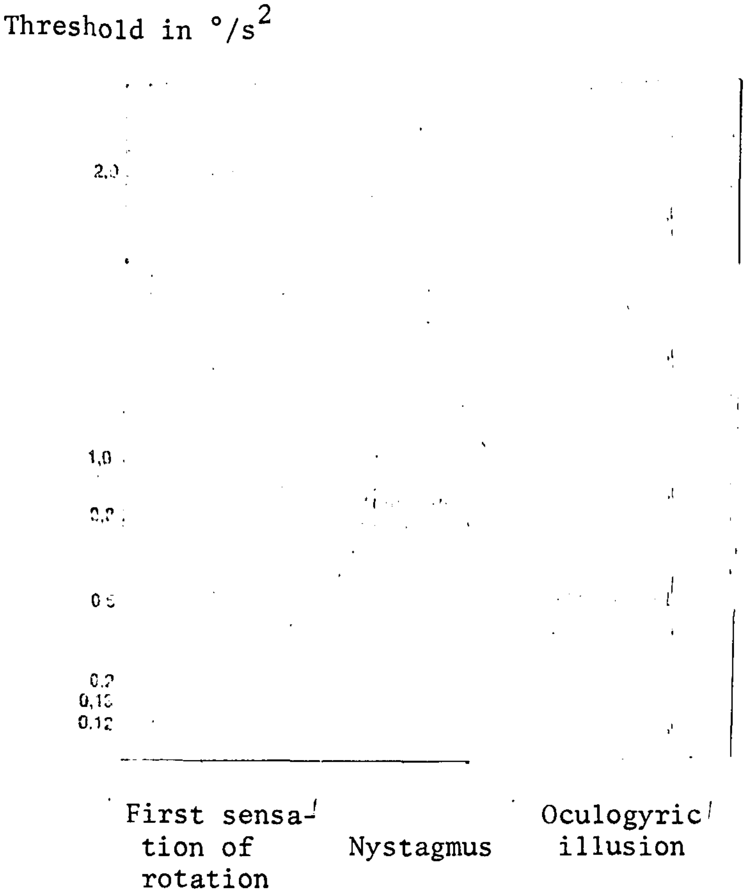


Figure 3. The Techniques Which Allow Measurement of the Thresholds for the Appearance of Vestibular Effects Caused by Low Frequency Oscillations are still Being Improved, and it is Noted that the Threshold Values Determined in This Way are Diminished at the Same Time. (According to Howard and Templeton, 1966).

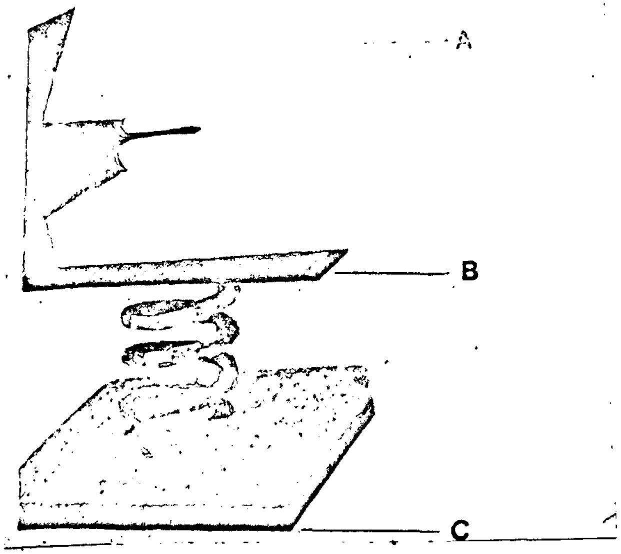
Experimental methods which allow the thresholds of appearance of these phenomena to be measured keep becoming more refined, and it is noted with surprise that the measured values keep diminishing. Thus, technical progress reveals the fact that the "alarm marks" are actually reached by stimuli much less intense than those recognized up to now. The important point of this research is having furnished quantitative data on what previously were only qualitative observations. This should not only permit prevention of difficulties associated with these vibrations, but should also allow evaluation of errors which a subject can make in perceiving his movements.

Biomechanical Effects and Muscular Responses /125

Thanks to the work of German research teams, it has been known since 1938 that when oscillation frequency exceeds 2 Hz, the human body can no longer be considered a uniform mass [6]. Vertical sinusoidal vibrations produce in a seated man relative displacements of bodily masses which are maximal at frequencies near 4 or 5 Hz.

These vibrations are terrible because of the numerous biomechanical and physiological effects which they cause: hyperventilation, vertebral stretches, intense jostling of the viscera, drop in visual acuity, etc. Now it is exactly in this frequency band that the distinctive oscillation frequencies of most terrestrial vehicles are found, farm tractors, trucks, handling equipment, etc. And this is what explains the many studies made by establishments of various purposes — farm machinery test centers, aerospace or military research laboratories, automobile and engine designers, public laboratories — in practically all the great industrial countries and even in certain predominantly agricultural countries. Clinical investigations established long before the causes could be perceived, an imposing list of pathological problems connected to each of the professional groups concerned. Nevertheless, the majority of the difficulties are due to the combination of several factors and vibrations only aggravated the situation. Spinal lesions and pains, for example, are the result of poor posture aggravated by intervertebral displacements caused by concussion. The research we have carried out in the work physiology laboratories of CNRS and CNAM at Paris had the purpose, not only to develop methods for recording vibrations on the ground, but also to understand the mechanisms of their action.

The reasons for which vibrations of 4-5 Hz frequency are the most terrible are related to the mechanical properties of the striated musculature of the /127 skeleton and to those of its nervous control. As a matter of fact, when the forearm of a subject, for example, is subjected to sinusoidal forces varying from 0 to 20 Hz, it is seen that he is able to keep it immobile except when the frequency is between 4 and 5 Hz [7]. Likewise, an oscillating force or even a transitory acceleration followed by deceleration, following at an interval of about 0.2 sec, risk causing an oscillation of the head which could be the source of cervical lesions like those observed in automobile accidents. In this particular case a strong vestibular stimulation can be combined with neuromuscular effects and lead to insufficient or unadapted responses of the neck musculature.



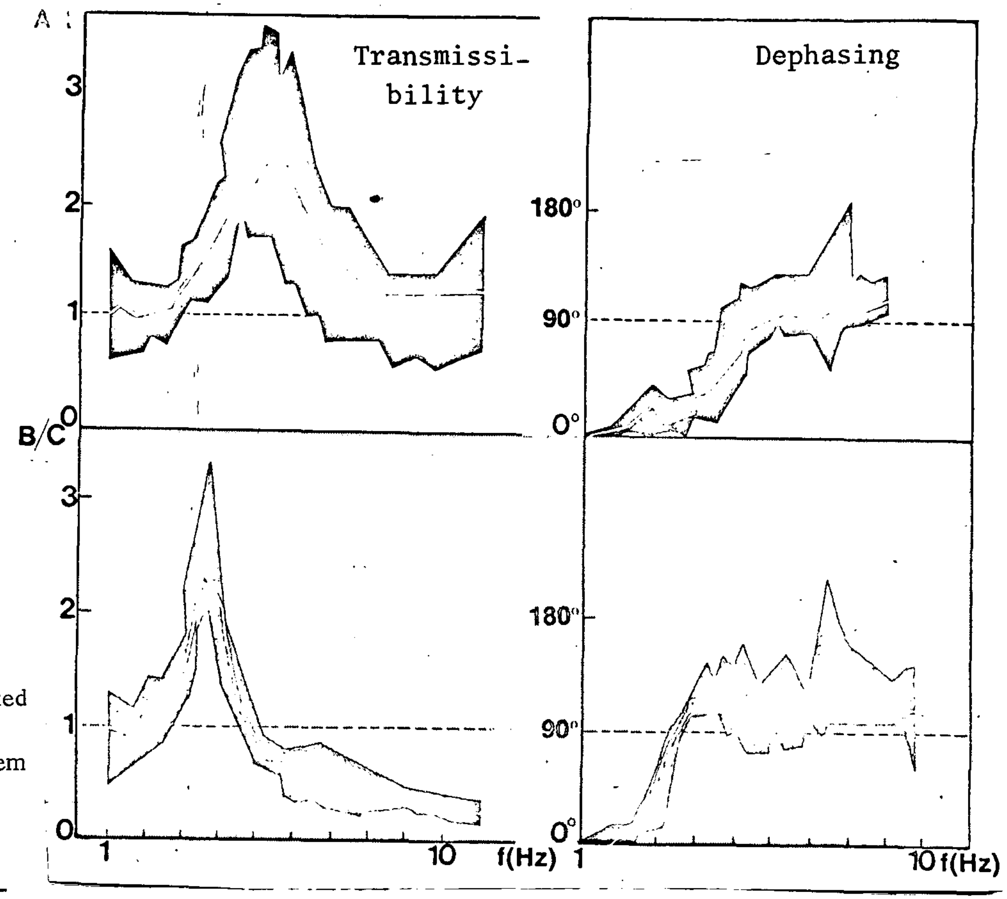
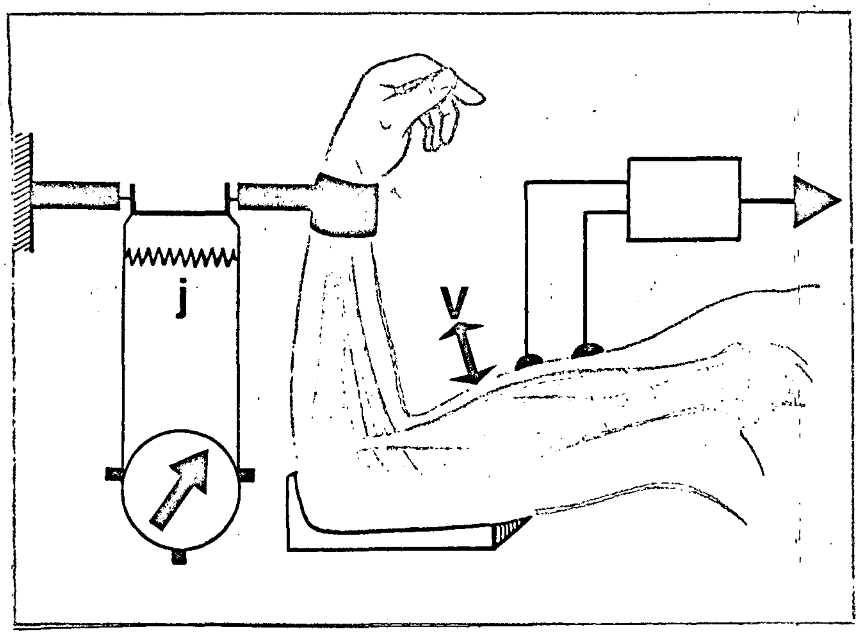


Figure 4. Danger at 4-5 Hz! When man is to be protected against the vibrations which he suffers on various vehicles, the laws of transmission of these vibrations through the system made up of the vehicle, the seat and the human body must be known. In this study, on a vibrating table, of the biomechanical properties of the human-seat system, man is compared to a system of masses (head, thorax, pelvis) connected to each other by springs and shock absorbers. By making use of different acceleration pickups on the vibrating table, the seat, the thorax and the head of the subject, it is possible to study the transmission of the sinusoidal vibrations through the seat and the body. In this way it is possible to determine the frequencies at which transmission between two pickups is most intense. Since the curves express, as a function of the vibration frequency, the ratios of amplitude of the accelerations (transmissibility) recorded at the level of the pickups of the table and of the seat on the one hand, and of the seat and the thorax on the other hand, they show that in the case of the body, transmissibility is maximum for frequencies between 4 and 5 Hz. It is also possible to determine the lags or dephasings between the movements of the different masses, table and seat on the one hand and seat and thorax on the other. In the body these lags which cause stretches and compression are particularly marked from 4 to 5 Hz. High transmissibility and significant dephasing make vibrations from 4 to 5 Hz the most injurious.



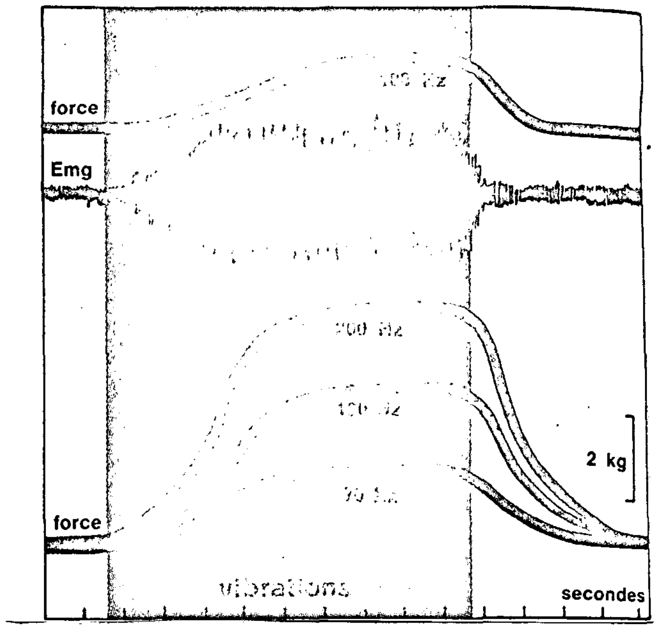
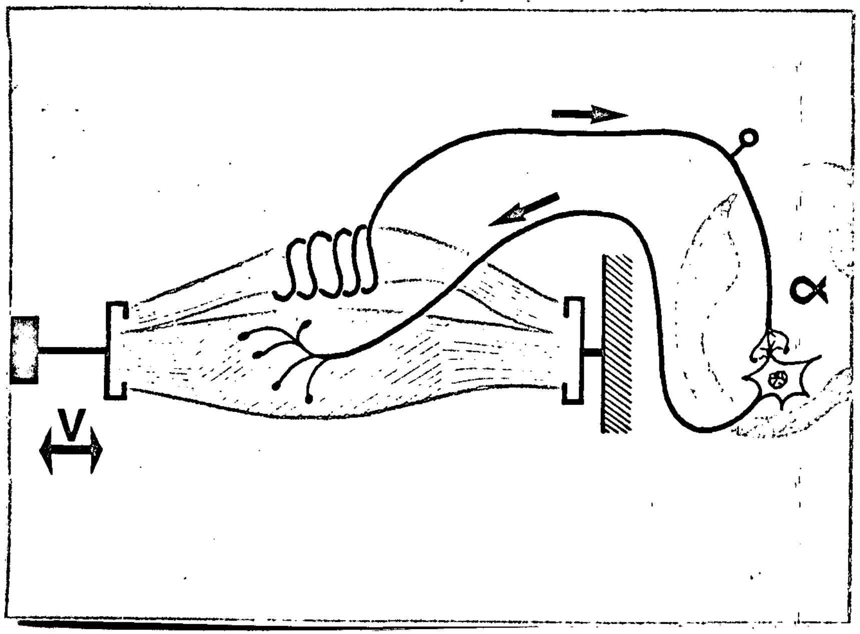


Figure 5. High Frequency Vibrations and Those of Motors are Essentially Perceived at the Level of the Skin and the Striated Muscles. The existence of many mechanical (motor) sources which provide high frequency vibrations has instigated the study of mechanisms of action of these vibrations on th- striated muscles.

Figure 5a. In Man a Vibration is Applied to the Biceps by means of a Mechanical Vibrator (V). The force is measured by a stress gauge (J) and the electrical activity of the muscles by electromyography.(EMG). During vibration at 100 Hz we observed a rise in the EMG and the appearance of a voluntary contraction with its amplitude reaching about 2 kg. If the vibration frequency is raised (70 Hz, 120 Hz, 200 Hz), the force of the involuntary contraction also increases. (According to Hagbarth).



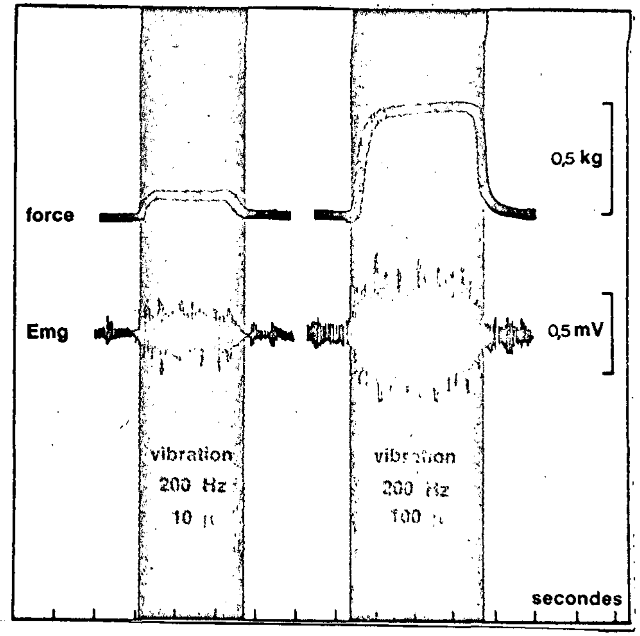


Figure 5b. The Mechanisms of this Tonic Contraction Have Been Studied in Cats. If a 200 Hz frequency vibration is applied to the tendon of an extensor muscle, the primary endings of the neuromuscular junctions are activated and reflexively stimulate the neurons which control muscle contraction (motoneurons). If the amplitude (10μ-100μ) of the vibration is increased, the intensity of the EMG activity and consequently that of the corresponding muscular contraction also increases. (According to Matthews, 1968).

In order to establish (as has been done in the case of noise) tolerance limits for this type of vibration, it would be necessary to know the exact ratios between the physiological effects observed and the amplitude of the vibration. These data are still extremely rare. Several countries have proposed to the ISO (International Standard Organization) some curves which anticipate the appearance of these difficulties. They give the limits for exposure to vibrations. As a matter of fact, their range is restricted because they are not based on sufficient experimental data to be definitive[1].

The essential point for prevention against this type of vibrations consits consists of damping their amplitude before they reach the human body. This can be done, thanks to measuring on the ground the mechanical properties of vehicles which is then completed in the laboratory by measuring the property of seats or protective devices. These techniques have been the subject of many studies of the ergonomic type and are beginning to be stingily adopted by the organisms and industries concerned.

Perception of High Frequency Vibrations

While vehicle movement in general leads to relatively low frequency oscillations, the engines themselves are the source of high frequency vibrations (>20 Hz). In addition, a large number of tools vibrate at high frequency (pneumatic hammers, trimming machines, etc) and cause recognized professional illnesses which depend on the frequency of the vibrations. These are essentially transmitted through the skin in the shape of shear waves. They are also propagated at a distance through the bones and, when the point of impact is the skull, can even produce auditory sensations.

The cutaneous perception of these vibrations has given rise since the end of the 19th Century to a controversy about the nature of the receptors involved. It was very early recognized that certain insects have a particular sensitivity to mechanical vibrations which transport data for them, and for a long time it was thought that analogically man could have a "vibratory sense." In reality, in man and mammals, perception of high frequencies is related to

[1]These curves are available in France from AFNOR (Association Francaise de normalisation: French Normalization Association).

the stimulation of a rather large number of mechanical receptors: receptors of muscular and tendon sensitivity, cutaneous and deep receptors, articular receptors. It was not until after 1950, despite the pioneering work of certain neurophysiologists such as Echlin and Fessard [9] in 1938, that the development of recordings of the nerve fiber activity in animals has produced precise information on this problem, at the same time as psychophysiological exploration developed in man. The team of Professor Mountcastle [10] in the United States has recently demonstrated the existence of two categories of receptors responsible for cutaneous vibratory perception and supposed to be situated at the surface and deep in the skin. Supposedly they would be respectively sensitive to vibrations with frequencies close to 40-60 Hz and 250 Hz.

Recording the activity of the nerve fibers stimulating the skin in monkeys has indeed shown that the receptors situated at the base of hairs were particularly sensitive to pressure variation oscillating around 40 Hz, while Pacini's corpuscles, lying deep, are stimulated to the maximum degree by frequencies near 250 Hz. This duality also exists in man, as is proven partly by the superposition of curves of subjective sensation with curves of activation obtained with monkeys, and partly by the fact that superficial anesthesia of the skin raises the sensation threshold of the human subject for low frequencies only, while it leaves high frequency perception intact.

All in all it may be peripheral properties are essential in the determination of vibratory sensation. Man has a remarkable capacity to determine the amplitude of a vibration. There is actually a linear relationship between the amplitude of the vibration applied and the subjective estimate made of it. Contrariwise aptitude to discriminate frequencies is very poor.

In addition to cutaneous perception, high frequency vibrations entail activation of the striated muscle receptors. At the same time Australian and Swedish physiologists [11] have shown that mechanical vibrations of 150 Hz frequency applied to the tendons of a skeletal muscle in man result in a lasting tonic reflex contraction and a reciprocal relaxation of its antagonists.

This is true for muscles of the higher and lower limbs when the vibration is applied to a tendon of flexors or extensors. This tonic reflex originates chiefly in the stimulation of the primary endings of the neuromuscular connections, stretch receptors situated along the muscles which are known to be very sensitive to vibrations in cats [12]. Nothing is known yet about the long-term effects of this contraction, but it is probable that it reacts at least on vascularization and participates in the appearance of illnesses such /128
as Raynaud's syndrome. This syndrome, the etiology of which is still not very clear, consists of vascular difficulties in the hands which are deprived of necessary compensation mechanisms upon exposure to cold and become white (whence the name sometimes used of "white hand syndrome.")

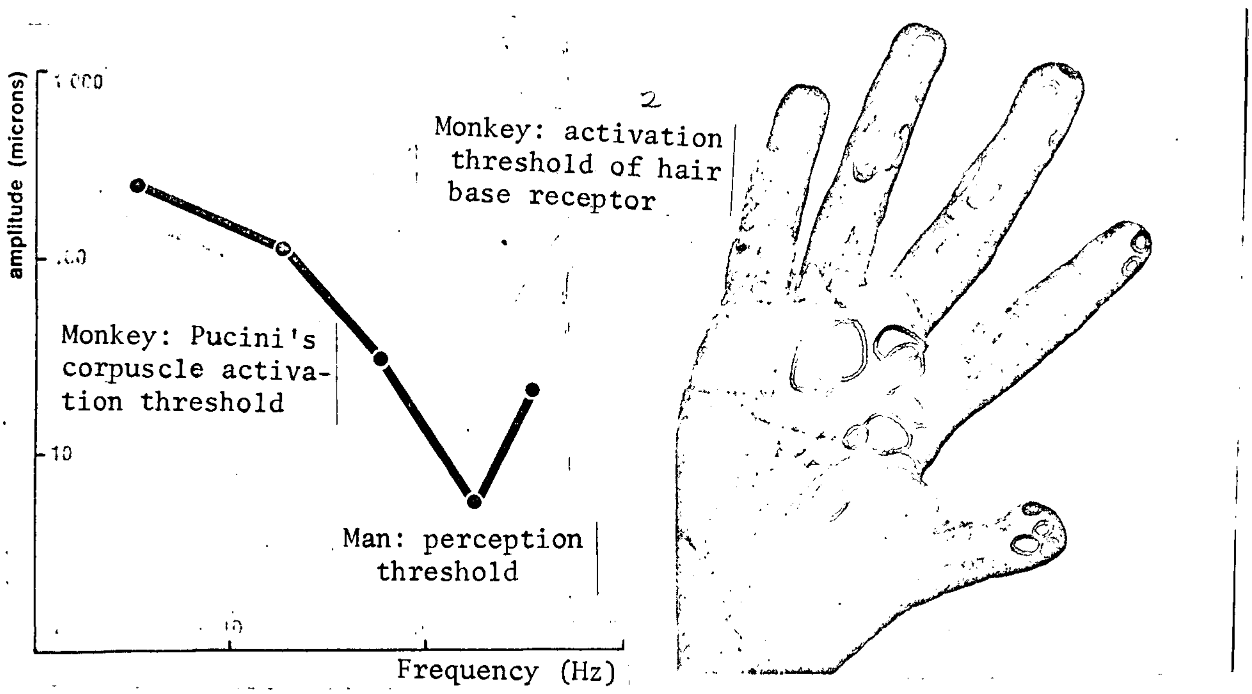


Figure 6. Cutaneous Perception of High Frequency Vibrations Can be Studied in the Monkey. Vibrators are attached at various points of the hand (photograph on right) or of the forearm and electrodes record the activity of the cutaneous nerves as a function of the amplitude and frequency of the vibration. In this way curves are obtained which indicate the activation thresholds of the different cutaneous receptors. The two curves obtained, one indicating a maximum sensitivity around 30 Hz and the other around 250 Hz, have been plotted on the diagram. These two curves correspond to two types of receptors. The curve of subjective perception thresholds in man has been superimposed on the preceding ones. (According to Mountcastle et al.).

Therapeutic and Scientific Application of Vibrations

From the Camera for the Blind to the Vibrating Drum, Vibrations are Also Capable of Beneficial Applications

Along with the problems connected with the perception of vibrations or with the origin of the difficulties which they cause, we must also envisage the use of vibratory stimuli for therapeutic or scientific purposes.

This picture of the effects of vibrations would be incomplete if it were limited to their harmful aspects. Oscillations or cycles of very low frequency, just because of their effect upon the labyrinth, have been used for a long time in clinical practice precisely to evaluate the integrity of the vestibular system. The most classic situation is the horizontal rotation of a subject on a chair, and nystagmus is used as an indicator of the functioning of the semicircular canals. At the present time oscillating pendulums are also used to test more precisely the otolithic organs which are particularly sensitive to linear accelerations.

Likewise the use of medium frequency vibrations is also anticipated in the treatment of certain diseases. Thus, a French urologist, Dr. Cottet, is exploring at the present time the possibility of making it easier to expel urinary calculi during diuresis treatment by exposing patients to mechanical vibration under medical supervision. The subjects with the calculi are seated on a stool which vibrates at about 10 Hz. Results obtained are encouraging because the treatment, apparently, facilitates elimination, change in position or fragmentation, even for calculi which have resisted traditional therapeutics, and this is done without causing nephritic colic or hemmorhage. The active mechanism of the vibrations is still hypothetical, but it is not impossible that, in addition to the purely mechanical action, there is produced a modification of the mobility of the smooth uretheral muscle under the effect of repeated stretching. Another example of the action of vibrations is the use with paraplegics of vibrators in order to empty the bladder. Here again, the mechanism is poorly known and the problem of their action on the smooth musculature, already mentioned, is found again.

In regard to the perception of high frequency vibrations, it has led to a series of attempts to use them as sensory substitutes or to mask pain. Among the most recent attempts, let us mention realization of a visual prothesis for those blinded by accident [13]. Objects are filmed by a television camera attached to a battery with 400 vibrators situated in the back of the blind subject. The activation of certain of these vibrators reconstitutes, point by point, the image of the object. This creation of a "tactile retina" produces impressions of real "vision" of the objects in the subjects. After being tested experimentally, this device has now been replaced by its authors by an electrical stimulation grid which suppresses mechanical transduction. This endeavor follows older attempts which had been made to specifically develop a /129
"language by vibrations" [14].

The action of high frequency vibrations on the striated musculature (vibratory tonic reflex) has suggested their use in the treatment of spasticity to Scandinavian researchers. The idea involved is the following: spasticity is demonstrated by an excessive stiffness of a muscle group A; if now a vibration is applied to antagonistic muscle group B, it causes a tonic contraction of this group B and, as a result of reciprocal inhibiting mechanisms, a relaxation of group A which was extensively stiff. The authors of this work claim to have obtained relaxation which lasted for a long time after the end of the vibration application. This offers a certain therapeutic interest, but may also put us on the trace of certain of the active mechanisms of vibrations in the field of preventive research.

Finally, some research of a psychophysical order have shown that the local application of high frequency vibrations could delay the appearance of pain caused, for example, by a burn. It must be stressed that the active mechanisms of these stimuli are poorly defined for the most part and that, as in the case for certain drugs, an agent can be beneficial in certain doses and harmful in others.

To conclude, let us say a few words about a very special use of vibrations as an experimental stimulus for scientific studies. For quite a long time the importance of using luminous oscillating stimuli to study vision has been recognized. Modern techniques of calculating the dynamic properties of a system suggest in fact that a sinusoidal stimulation be applied to this system and that the signals obtained at the "exit" of the system be compared to those applied at entry. In this way transfer functions are deduced. Likewise, in order to study the motility of mechanical receptors, we tend to use oscillating mechanical stimuli as "entry signals." Thus vibration becomes not only a source of harm, but a powerful tool for scientific investigation.

There are still many questions to be answered, as can be realized from what has been said. On the level of mechanisms, it is still necessary to better understand how the nervous system treats the data which it receives from the periphery, how data are compared with one another, and how mechanical vibrations interfere with the other physical modalities of the environment. A large part of the biomechanism of dynamic and biochemical perturbations of the bones and tissues remains to be studied, as well as the physchological consequences of certain perceptive kinds of confusion. As far as the possibilities of application to therapeutic ends or for neurological exploration are concerned, they are still in their infancy.

The development of research concerning these problems is promising, but large obstacles await us, both to extend our knowledge and to apply the knowledge acquired. This is because this research requires frequently expensive devices which generally only paramilitary organisms have been able to construct or organisms connected with aeronautics or which correspond to matters of a technical not medical order. Now, frequency bands and amplitudes, and other factors of the environment, are very different in an airplane flying at high speed and low altitude, on a farm tractor, or in a public transportation vehicle. Very real efforts have been made by various nations to transfer data obtained in one place to industrial situations involving a large number of workers. But research which is valid under certain conditions (frequency band, amplitude and points of application on the body) are not, as we have shown in this text, always applicable under other conditions.

This leads, for example, to the revealing fact that pneumatic hammers which cause serious and recognized professional illnesses are certainly machines for which the least amount of research has been done; on the other hand, airplanes, rockets and automobiles have been the subject of infinitely more work. This does not mean that a large number of institutes have not made efforts in this direction. But real progress in prevention cannot be made without a rather radical transformation of perspective and without really applying the improvements placed here and now at the disposition of practitioners by ergonomic research. In the same way, the researchers finds a certain difficulty in a society completely organized around profit in asking not only for consideration of lessened performance connected with exposure to vibrations, but also, and perhaps especially, long-term disturbances of the mental and physical health of the subjects who endure them — disturbances which often escape subjective jüdgement.

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Translated for the National Aeronautics and Space Administration under contract No. NASw-2037 by Techtran Corporation, P. O. Box 729, Glen Burnie, Maryland 21061, Translator: Lawrence W. Murphy, Ph.D.